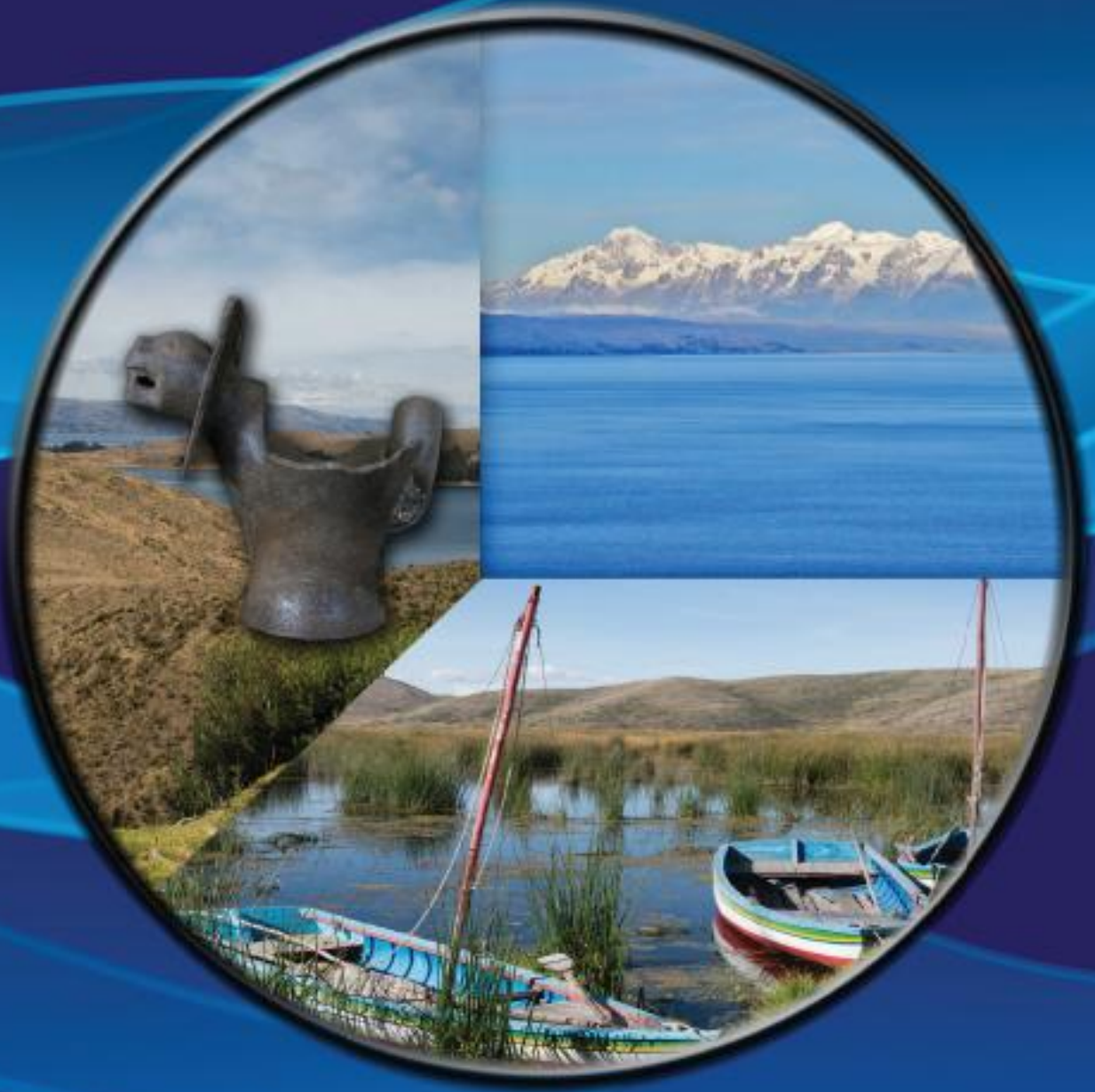
COLOQUIO INTERNACIONAL SOBRE LA CONTAMINACIÓN ACTUAL E HISTÓRICA EN LOS ECOSISTEMAS ACUÁTICOS ANDINOS



La Paz, 3 al 5 de mayo de 2016
Universidad Mayor de San Andrés, Cota Cota, La Paz

Proceedings

International colloquium on current and ancient contamination in Andes aquatic ecosystems

Coloquio internacional sobre la contaminación actual y histórica en los ecosistemas acuáticos Andinos

Colloque international sur la contamination actuelle et historique des écosystèmes aquatiques andins

La Paz – May 3rd – 5th 2016

Universidad Major de San Andrès – Campus de Cota-cota, La Paz

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General Planning

- **May 3rd 2016: Contamination and eutrophication of Lake Titicaca**

AM session: Mercury biogeochemistry and contamination of aquatic ecosystems of the Andes region
Keynote Lecture: Hg contamination in Latin America: the past is not what we think, nor the future (J.-R. Davee Guimarães).

PM session: Chemical contamination, eutrophication and monitoring of Lake Titicaca and its watershed
Keynote Lecture: Eutrophication of the Cohana Bay (D. Acha).

- **May 4th 2016: Arsenic issues in the Andes**

AM session: Arsenic biogeochemistry and contamination of aquatic ecosystems of the Andes region
Keynote Lecture: Arsenic contamination of groundwater (Chile) (G. Lobos).

PM session:
Workshop 1: Arsenic and mercury speciation.
Workshop 2: Paleoenvironmental studies in the Andean altiplano.

- **May 5th 2016: Historical reconstructions of the human-climate interactions in the altiplano: implication of archeological purposes**

AM session: Paleo-environmental reconstruction of Altiplano's archives
Keynote Lecture: Holocene Paleoclimatic and Paleoenvironmental History of the Lake Titicaca Basin (S. Fritz & P. Baker).

PM session: Archeology: historical human – environment interactions
Keynote Lecture: Recent contribution of terrestrial and subaquatic archeological investigation in Lake Titicaca (C. Delaere & M-A. Vella).

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Session 3: Historical reconstructions of the human-climate interactions in the altiplano: implication of archeological purposes

Session 3.a. Paleo-environmental reconstruction of Altiplano's archives

Session 3.b. Archeology: historical human – environment interactions

Session 1: Contamination and eutrophication of Lake Titicaca

Session 1.a. Mercury biogeochemistry and contamination of aquatic ecosystems of the Andes region: case study in Lake Titicaca and Uru Uru

Keynote lecture
Hg contamination in Latin America: the past is not what we think, nor the future

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Abstract:
Artisanal small-scale gold mining (ASGM) is a central economic activity throughout the developing world, involving over 13 million people; however, it leads to extensive pollution of waterways through the use of Hg to extract gold. Studies conducted in the Amazon show elevated levels of Hg in fish and sediment downstream of ASGM sites however, there is no definitive scientific evidence showing Hg in specific aquatic ecosystems is from Hg use in ASGM, rather than from other sources such as erosion. To verify if stable Hg isotopic analysis can trace sources of Hg through aquatic ecosystems, we focused on Hg pollution of waterways in a former gold mining area in Amapá, Brazil and on an active mining and processing area in the Puyango river, southern Ecuador. Total Hg as well as Hg isotopic composition was measured in sediment, SPM and soil samples upstream and downstream the mining areas. Hg from all samples was trapped via combustion using a Leeman Labs Hydra-C mercury analyzer. Both mass-independent and mass-dependent isotopic Hg signatures were analyzed using cold vapor multi-collector inductively coupled plasma mass spectrometry (CV-MC-ICP-MS). The data from Amapa demonstrate that although ASGM is associated with elevated Hg concentrations near (< ~2 km) the ASGM site, elemental Hg used during the amalgamation process is not predominant downstream. The latter has a unique isotopic signature observed near the ASGM site but not farther downstream nor in sediments of downstream Duas Bocas lake, with elevated Hg (2 to 3 x more than a nearby non-polluted lake) suggesting that the elevated Hg in the lake is from erosion and runoff, likely due to land-use change associated with ASGM, agriculture and cattle production. In the Puyango, Hg from mining also has an isotopic signature that is distinguishable from the one from background and upstream sites, but in contrast with the Amapa region, all river samples from the processing centres down to the estuary, ~ 300 km away, are clearly from mining origin. This a transboundary issue as the Puyango, named Tumbes in Peru, is the only public water supply for this area of the northern peruvian coast and also supports irrigated rice and banana plantations. The differences observed in mining influence on local Hg concentrations reflect the contrasting studied settings, with Amapa representing the case of a weak Hg signal in a region with high natural soil Hg and erosion and a high water flow, while the Puyango illustrates the exact opposite. The influence of gold mining in recent Amazon sediments seems to have been overestimated, while the impacts of Andean mining activities on downstream systems has been underestimated. Cyanidation is being increasingly used in most gold mining areas but little is known about its impacts and about Hg-cyanide interactions.

National mercury assessment baseline in Bolivia

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Abstract:
We initiated a baseline study and inventory of mercury (Hg) releases, a harmful neurotoxic pollutant, in Bolivia. Identification of Hg sources and preliminary quantification of Hg releases were estimated using the UNEP Hg toolkit. Our preliminary results show an annual average emission of 133 t of Hg (ranges from 44 to 229 t). According to these estimates mining activities represent roughly 70% of the potential Hg emission. More than half of this quantity came from mercury used in artisanal and small scale gold mining (extracting fewer than 500 t/day). The use of extraction/refining products and production of mine wastes that contain Hg represent significant amounts (17% and 7% respectively). However these preliminary estimates should be viewed with caution because of the lack of reliable information on these often informal mining operations which contributes to a broad error range. Moreover these estimates should be compared with the significant amount of 14 t Hg (10% of total emissions), which is the product of soil Hg liberated by erosion and transported from the Andes to the Amazon region, an area more favorable to transformation of elemental and inorganic Hg into the more biotoxic form methylmercury. However some reports show higher ranges of MeHg production in the Andean region that may indicate direct inputs of these pollutants from the mining operations there.
Hg levels in fish and human populations do not appear critical nationally, but in some cases exceed the standard safe intake levels recommended by WHO. However, the inventory of Hg levels in humans and the natural biota also lacks specific information to infer a global view of Hg contamination for Bolivia. In general, the available information was concentrated in the region where high artisanal gold mining activity was developed, such as in the Andes and some main rivers of the Amazon region (Beni, Itenez and Pilcomayo).
Here we present a preliminary map of Hg contamination risk exposure to demonstrate the gap between the potential contamination risk and the actual distribution of Hg studies. Critical lack of studies and assessments about mercury levels was depicted in some important regions of the Amazon with high risk of mercury pollution such as Pantanal and Madre de Dios. Our map suggests that new research is needed to improve the data on Hg in these areas.
Finally we recommend 1) to improve and deepen the inventories of Hg in order to achieve more accurate estimation of emission sources and the fate of mercury in the environment, 2) to develop a spatiotemporal monitoring of mercury levels in fish and humans and 3) to implement policies to prevent the contamination of the biota and human populations. A national political organization, such as a dedicated a secretary, may be necessary to achieve these goals.

Mercury bioaccumulation in high altitude lake ecosystems of the Bolivian Altiplano region (Lake Titicaca endoreic basin)

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Abstract:

Methylation and biomagnification of mercury (Hg) are well documented in most aquatic ecosystems. Few data exist in high altitude lake ecosystems, in particular from the Bolivian Altiplano region. Recent work performed in the framework of the INSU COMIBOL and ANR LAPACHAMAMA projects were conducted in Lake Titicaca and Lake Uru-Uru, where Hg analysis, and trophic tracer (stable isotope of $\delta^{13}C$ and $\delta^{15}N$) were determined in different compartments.

Both lakes are located in a semiarid region and form part of the endoreic bolivian-peruvian Titicaca catchment located at 3800m. Lake Uru-Uru is directly connected to Lake Titicaca by the Desaguadero River, it also has additional tributaries polluted by effluents of mining and urban origin.

In lake Uru-Uru, stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of the different compartments showed that the bottom sediment (organic matter) was the most important carbon source for the food webs. Macroinvertebrates were preferentially primary consumers, showing intermediate mercury concentrations (0.2 – 0.4 mg/Kg). The higher trophic positions were represented by fishes (*Orestia* spp.) and piscivorous waterbirds (*Rollandia rolland*) respectively, showing the highest Hg concentrations (>0.5 mg/Kg).

In lake Titicaca, the same foodweb structure was observed as in Lake Uru-Uru. A significant Hg bioaccumulation trend was observed, although Hg concentrations at each trophic level were much lower than in Lake Uru-Uru. Spatiotemporal analysis of Zooplankton among 4 different sites in lake Titicaca showed the highest concentrations in the Cohana bay (0.1 mg/Kg), likely reflecting the influence of El Alto city effluents. Mercury concentrations were found much lower in the Lago Grande region (Isla de la Luna, 0.020 mg/Kg) and at two other stations in the Lago menor (Chua, Huatajata 0.025 mg/Kg). Two-year monthly monitoring survey at these two last sites showed that Hg concentrations in zooplankton vary seasonally ranging between 0.010 and 0.050 mg/Kg.

Comparison among the two lake systems shows that Hg levels in the food webs were directly related to the net production of Methylmercury (MeHg) at the base of each lake system. Lake Uru-Uru showed MeHg dissolved concentration of approximately 700±100ng/L, compared to 55±50 ng/L in Lake Titicaca. This difference likely reflects a higher Hg methylation in lake Uru-Uru compared to Lake Titicaca where MeHg photodegradation is enhanced (confirmed by Hg stable isotope analysis). In both lakes, Hg transfer and biomagnification along the trophic structure (from source to top predator) was observed. These results show that mercury methylation processes are significant in high altitude lake ecosystems.

Biogeoquímica del mercurio en el lago tropical de altura Uru Uru (Altiplano boliviano)

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Abstract: En la región del Altiplano boliviano, de condiciones ambientales extremas (3700 m.s.n.m. de altitud, elevada radiación UV, menor disponibilidad de O2), se encuentra el lago Uru Uru. De aguas poca profundas (0-1 m), elevada gradiente en la salinidad de sus aguas y alta productividad primaria, es impactado por descargas de afluentes mineros y urbanos. Las elevadas concentraciones de monometilmercurio (MMHg), un neurotóxico muy potente, medidas en peces y aves (Molina et al., 2012), ha cuestionando la fuente y transformaciones del Hg para la producción de MMHg en los ecosistemas de altura. La producción de MMHg es un proceso clave que dirige la bioacumulación del Hg en la cadena alimentaria y los procesos de metilación y demetilación, son los mayores patrones de transformación que regulan la producción neta de MMHg.

Para dar respuesta a estas preguntas concentraciones de metales, metaloides (Fe, Mn, Sb, Ti y W), elementos mayoritarios, especies de mercurio (mercurio inorgánico (IHg), MMHg, mercurio vapor (Hg°) y dimetilmercurio (DMHg)) fueron medidas en muestras de aguas; MMHg y mercurio total (THg) en sedimentos y aguas intersticiales de sedimentos del lago Uru Uru. Al mismo tiempo se realizó un seguimiento de la distribución espacio temporal de Norte a Sur del lago, para todos estos parámetros, durante las épocas seca y húmeda (octubre, 2010 y mayo 2011).

Además se determinó los potenciales de metilación (M) y demetilación (D) en situ en muestras de sedimentos, aguas, periphyton y agregados bio-orgánicos flotantes en los sitios norte (NS) y sur (SS) del lago Uru Uru, utilizando trazadores isotópicos estables de ^{199}Hg y $MM^{201}Hg$.

Entre los resultados más importantes se encuentra la elevada concentración de metales pesados y de MMHg en forma disuelta, la cual llega hasta el 49 ± 11 % con respecto al mercurio total disuelto (THg_d). Se identifica a los sedimentos como la fuente principal de MMHg, cuyo flujo difusivo alcanzan hasta 227 ng m^{-2} day^{-1} de MMHg durante la época seca. Esta aseveración es sustentada con la medición de los potenciales de M/D en las diferentes matrices.

Los potenciales Netos de M, medidos en el sitio Norte, indican que los efluentes mineros y urbanos promueven la producción de MMHg en las aguas y en los sedimentos (3,4±1,2 ng g^{-1} day^{-1}) durante la época seca. Si bien se identifica a los agregados bio-orgánicos como los mayores productores de MMHg (5,8 ng MMHg g^{-1} day^{-1}, época seca), son los sedimentos los mayores representantes de producción de esta sustancia tóxica, tomando en cuenta la diferencia de masa total de cada matriz en el lago. Se determina también que el rol del periphyton de las totoras es el de la descomposición de MMHg (-2,1 ng MMHg g^{-1} day^{-1}), pero también el de almacenamiento de MMHg.

En suma se demuestra que existe un efecto sinérgico de los drenajes ácidos mineros (DAM) según la temporada y los efluentes urbanos en los ecosistemas productivos, al cual la evaporación superficial promueven las elevadas emisiones de contaminantes organometálicos como MMHg en la columna de agua, cuya producción y la estabilidad se nutre de la abundante materia orgánica y de los ligandos presentes en el medio.

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Processes controlling Methyl-Hg formation and degradation in Lake Titicaca hydrosystem (Bolivian Altiplano)

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Abstract:
The aim of the project LA PACHAMAMA (Franco-Bolivian project) was to investigate the biogeochemical cycling of Hg in the high altitude hydrosystem of Lake Titicaca (TDPS), combining integrated ecological approaches, and information on the molecular speciation and isotopic composition of Hg. These extreme lake ecosystems display unique biogeochemical features such as high altitude, significant productivity, high UV radiations and low oxygenated waters that are likely to stimulate significantly both the production and degradation of MeHg. Different representative sites were selected to constrain the role of aquatic plants (totoras), benthic biofilm and macrophytes (characeæ), or water column processes. These sites have been investigated during 2 intensive field campaigns in April/May and October/November 2014. Lake water samples were collected at different locations and depths in the water column. MeHg behaviour at the sediment-water interface was also investigated to assess the influence of benthic biofilm and macrophytes present at the sediment surface on MeHg productio. The transformation pathways were further constrained using in situ incubations with enriched isotopic tracers. Overall the preliminary results show that in this specific ecosystem, the intense benthic biological production, triggered by potential eutrophication, is probably a major contributor to the formation of MMHg and its transfer into the food chain, while intense UV-light radiations may control MMHg content in the water column. This study allows performing a first assessment of Hg contamination source and fate in the lake Titicaca hydrosystem.

Methylmercury production and exchanges in sediments of Lake Titicaca

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Abstract :

Lake sediment is known to be an important source of the neurotoxic monomethylmercury (MMHg) for surface water (Fitzgerald et al., 2014), in which trophic transfer occur in both benthic and pelagic organisms (Watras et al., 1998). Geochemical processes involved in the methylation of mercury (Hg) generally occurs in surface sediment or biofilms developed at the sediment/water interface (SWI) and imply various micro-organism amongst which the most documented are sulfate reducing (SRB) and iron reducing (IRB) bacteria (Benoit et al., 1999). Such processes occur specifically during early diagenesis, when a part of deposited fresh organic matter (OM) is mineralized close to the SWI, with O_2, NO_3^- , Fe- and Mn-oxyhydroxides or SO_4^{2-} acting as electron acceptors (De Lange, 1986; Froelich et al., 1979).

In this study, we provide a high resolution (mm scale) complete Hg speciation, major and trace elements in porewater and solid sediment from seven short core collected in Lake Titicaca.

Total Hg concentrations in sediment of Lake Titicaca are low in both shallow (depth < 10 m, THg = 23 ± 14 ng g^{-1}, N= 110) and deep areas (depth > 10 m, THg = 52 ± 52 ng g^{-1}, N= 101) with MMHg concentrations representing 2.9 ± 6.7 and 0.3 ± 0.1 %, in shallow and deep areas respectively. In opposition to sediment, MMHg concentrations are elevated in porewater, especially in shallow sulfate and carbonate rich sediments (2.2 ± 1.8 ng L^{-1}), where SRB are the likely major methylating organisms. Calculation of diffusive fluxes, highlighted very high MMHg diffusive fluxes being 91.8 ± 13.8 and 13.2 ± 2.0 ng m^{-2} d^{-1} in shallow and deep areas, respectively. Such fluxes would represent around 30 % of the MMHg contribution to the water column of Lake Huiñaimarca. Therefore, the major outcome of this study is that although THg concentration in sediment are low, the shallow carbonate facies and sulfate rich sediment are a major source of MMHg to the water column of the small Lake Titicaca (Huiñaimarca).

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MUESTREADOR *IN SITU* PARA LA DETERMINACIÓN DEL METILMERCURIO EN SISTEMAS ACUÁTICOS

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Abstract

La determinación de la biodisponibilidad del Metilmercurio (MeHg) presente en sistemas acuáticos es importante como estudio de la evaluación de riesgos que se expone la biota y así estimar el impacto en la salud humana. Para este propósito, se desarrolla un muestreador con tecnología de recubrimiento de nanopartículas 3-MPTS con una mayor sensibilidad para preconcentrar el MeHg par una rápida extracción y determinación de cantidades ultratrazas en muestras de aguas naturales. Este sistema de muestreo tendrá la facilidad de transporte y reducción en costos.

Session 1.b. Chemical contamination, eutrophication and monitoring of Lake Titicaca and its watershed

Keynote lecture

Nuevas luces sobre la eutrofización del Lago Titicaca, perspectivas de remediación y monitoreo

New lights on Lake Titicaca eutrophication process and perspectives about monitoring and remediation.

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Abstract:

Titicaca Lake is among the largest and most important lakes of the world, its tropical latitude and high altitude (3850 m.a.s.l) makes it a unique ecosystem and a conservation priority. However, the shallow part of the lake (Lago menor) collects sewage water from about two million people and there is little information about the extent of the contamination or degree of disturbance caused to the ecosystem. We investigated different abiotic and biotic markers of eutrophication in a transect from the main source of contamination at Bahia Cohana to an apparently less impacted area. We investigated the largest bloom ever recorded in the lake, monitored closely physicochemical and biological changes in the ecosystem for more than four years and explored some of the major factors controlling carbon biogeochemistry. We found a natural succession of macrophytes limiting dispersion of contaminants out of Bahia Cohana and attenuating ecosystem impacts such as a change in pH, which changed more than two units in the most impacted area. Using this gradient we identified nitrogen and carbon isotope fractionation as the most reliable and sensitive markers for eutrophication. Attenuation of light penetration, pH and oxygen close to the sediments were also good indicators of eutrophication. We found that areas not directly affected by Katari river discharges are also polluted and that significant amount of pollution could be attributed to local communities' discharges. Physicochemical analysis revealed that the ecosystem is naturally enriched with sulfate, making it prompt to hydrogen sulfide production. The dominant algae during the bloom was identified as *Carteria sp.* a Chlorophyte genus closely related to *Clamidomonas* with no report of toxicity, but which may have caused significant water toxicity (indicated by the death of large numbers of amphibians, fish and even birds) by indirectly promoting an increase in hydrogen sulfide production. Our continuous monitoring program revealed that the ecosystem has suffered significant changes in the las 15 years. It also showed that small algae blooms were continuously occurring causing picks of oxygen production during the day and unusual low concentrations during the night. Our analysis also showed that Charophytes have a significant role in the lake. They produce oxygen in the bottom of the water column preventing H_2S dispersion and making the lake a sink for CO_2. In polluted areas Characeae die off and the lake becomes a source of CO_2 to the atmosphere. Now we are starting two pilot studies to identify the best alternatives for continuous monitoring of the lake and to generate sustainable alternatives to mitigate the impact of local communities on the lake. We will test macrophyte and periphyton associated ability to reduce or contain the nutrient enrichment of the lake in two different scenarios. The first will be directly at the lake with a floating island with containing the macrophytes and the second a more traditions wetland approach at the Katari river.

Mercury accumulation in periphyton associated to macrophytes and its relationship with eutrophication in Cohana Bay

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Abstract:

Methylmercury (MeHg) is one of the most toxic forms of mercury, due to its capacity to bioaccumulate and biomagnify within the trophic chain. Mercury methylation is mostly linked to bacterial activity and so far SRB (sulfate reducing bacteria) are considered the main methylators in anoxic sites. In aquatic environments, periphyton associated to macrophytes has proven to play an important role in both, production and accumulation of MeHg. Therefore, this research studied the relationship between eutrophication and MeHg found in periphyton associated to macrophytes in Cohana Bay. This particular area located in Titicaca Lake has an ongoing eutrophication process, due to wastewater discharge coming from Katari River. Because of this situation, Cohana Bay has an anoxic environment that allows the activity of bacteria, such as SRB. Thus, in order to established a relationship between SRB activity linked to eutrophication and MeHg accumulation found in periphyton associated to macrophytes, samples of periphyton were collected along an eutrophication gradient in two trips (april and september). The samples were divided so that they could be analyzed for MeHg, total mercury (HgT) and SRB activity. Given the high content of organic matter in periphyton, a Selective Extraction Method (SEM) that allows recovering most of MeHg within a sample for later analysis, was validated. Results showed that in spite of SRB activity being detected in periphyton associated to macrophytes, there is no relationship with MeHg accumulation. At the same time, other parameters such as: HgT and isotopic composition were considered in order to see a possible relationship with MeHg accumulation. Only the samples collected in april showed a significant relationship between MeHg with HgT and $\delta^{13}C$ (‰). The lack of a relationship between MeHg and eutrophication indicator isotopes of $\delta^{15}N$ (‰), confirmed that in Cohana Bay MeHg accumulation in periphyton associated to macrophytes is not related to eutrophication; rather other factors like periphyton composition could influence in this.

Bioacumulación de mercurio y metilmercurio en biofilms de algas, en dos zonas con distinto estado trófico del lago Titicaca

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Resumen

Uno de los contaminantes más peligrosos por sus niveles de toxicidad es el mercurio, metal pesado que se encuentra ampliamente distribuido en el ambiente de manera natural, el problema se genera cuando, por acciones antropogénicas, se modifica su ciclo natural y se afecta sustancialmente a los ecosistemas al aumentar sus niveles de toxicidad. (Langer, 1992).

Las formas metiladas (metilmercurio Me-Hg y dimetilmercurio DMeHg) son las más toxicas; ya que, éstas tienen la capacidad de acumularse y afectar sobre todo al sistema nervioso. (Ullrich et al., 2001).

Según Desrosiers, et al. (2006), el principal lugar donde ocurre la metilación (transformación de mercurio a metilmercurio) es en el perifiton, conformado por algas, bacterias, hongos, microinvertebrados y detritos, siendo éste un productor primario.

Las elevadas concentraciones de mercurio podrían afectar la composición de algas, en sus niveles de mortalidad, en la tasa de crecimiento o incluso en la inhibición fotosintética. Además en su densidad, riqueza de especies y abundancia relativa (Peres et al., 1997).

Otro factor responsable de una gran variedad de efectos nocivos en los organismos autótrofos acuáticos, es la radiación solar ultravioleta (Vincent, 1993) que afecta especialmente a las diatomeas debido a su pequeño tamaño (Garcia, Pichel, 1994). Estos efectos influyen también en la inhibición de la fotosíntesis (fotosistemas I Y II) del fitoplancton (Cullen et al., 1992), alterando la producción primaria y; a su vez contaminando los sucesivos niveles de la cadena trófica por efecto de la bioacumulación. Una de las vías para establecer la presencia de mercurio en el perifiton es el muestreo cuantitativo en sustratos naturales. Sin embargo, es un muestreo difícil de realizar, por presentarse en superficies muy heterogéneas, dificultando la cuantificación. Por tal razón, el muestreo se realiza en sustratos artificiales que facilitan la formación de biofilms semejantes al perifiton. Este biofilm incubado será un indicador de situación de riesgo relativo a la presencia o no del contaminante; ya que, permite detectar la presencia de agentes tóxicos que pueden ser bioacumulados (Marshall, 1992). En tal sentido, la presente investigación pretende evaluar la composición de algas en los biofilms de perifiton en relación a la radiación solar para establecer en qué medida estos aspectos influencian en la bioacumulación del metilmercurio en biofilms. Además de evaluar la relación entre la composición de algas y las concentraciones de metilmercurio en biofilms desarrollados en dos zonas con diferente estado trófico y el efecto de la radiación solar en el crecimiento de biofilms y la acumulación de metilmercurio en dos áreas con distinto estado trófico del Lago Titicaca, como son la Bahía de Coana (Eutrófico) y Huatajata (Oligotrófico).

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Sedimentary sulphate reducing bacteria activity through a gradient of eutrophication in Cohana`s bay

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Abstract:

Eutrophication is a highly complex environmental problem and the responses to nutrient inputs between environments can exhibit substantial differences of magnitude and trajectory. The eutrophic aquatic environments could have an imbalance in their carbon and sulphur cycles, where the sulphate reducing bacteria (SRB) may play an important role. The SRB can anaerobically degrade completely the organic matter producing hydrogen sulfide (H_2S), a toxic substance that can provide a positive feedback to eutrophication. Because of its high altitude, shallow and tropical location, Titicaca Lake is vulnerable to eutrophication and its sulphate enrichment of geological source could promote the SRB activity in the sediments. Cohana`s bay is second most contaminated area of Titicaca lake and receives a Katari`s watershed discharge that encompasses mining area, a huge city (representing over 1.2 million habitants), and agricultural zones before ending in Cohana bay. In this study, a possible eutrophication gradient has been determined by a transect starting near Katari´s river mouth until some kilometers into the lake. Along this transect where measured some physico-chemical parameters of the eutrophication, such as, pH, dissolved oxygen, dissolved organic carbon have been analyzed and the activity of SRB was measured indirectly by the detection of hydrogen sulphide (H_2S) through a colorimetric technic to measure quantitatively the *in situ* concentration near the sediments. Additionally the presence of some general groups of SRB was determined by FISH technique. In the case of Cohana Bay, it is evident that a gradient of eutrophication exists and that the higher level of eutrophication is near the Katari´s river mouth. Also, the gradient is enriched with sulphate and the SRB activity was influenced by this eutrophication gradient. Finally the H_2S was a good indicator of eutrophication and both FISH technique and the incubations with molibdate confirmed the presence and activity of SRB in the sediments.

Carbon and nitrogen isotopes as tracers of eutrophication in Bahia Cohana (Lake Titicaca)

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Anthropogenic reactive nitrogen (Nr) inputs from land to aquatic ecosystems lead to eutrophication processes that are difficult to handle and even harder to remediate. Establishing the source and fate of nutrients and pollutants has shown to be challenging, especially in alpine lakes where information is scarce and where spatial and temporal monitoring is needed for eutrophication control and management. To fill this gap, we examined the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope fractionation in primary producers (macrophytes, particular organic matter, periphyton) and in sediments along an eutrophication gradient in Cohana Bay and its surroundings in the southeast shallow productive part of Lake Titicaca (3812 m). Samples were collected during late wet season (April 2013) and late dry season (September 2013). In all cases, the $\delta^{15}N$ was negatively correlated with distance from Nr inputs (Katari River). The $\delta^{13}C$ was positively correlated with distance only in the case of macrophytes, particulate organic matter and sediments. The $\delta^{15}N$ distribution pattern suggests that primary producers are assimilating anthropogenic N that arrives to the lake and that this Nr is mainly from wastewater origin. The $\delta^{13}C$ spatial pattern suggests that carbon assimilation near the earth-water margin is predominantly allochthonous. We conclude that the eutrophication process can be tracked with isotopic parameters and that this process is still confined to Cohana Bay. This work shows the effectiveness of using C and N stable isotope fractionation as markers for monitoring the eutrophication processes in an alpine lake.

Antibiotics contamination in the Katari watershed and impact assessment in the context of the Bolivian Altiplano

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The Katari watershed (2022 km^2) encompasses the biggest population of the Altiplano and has its outlet in the Cohana bay located in the Titicaca Lake (Huiñamarca Lake). This bay presents the most eutrophic waters of the Bolivian part of the Lake (Fonturbel, 2005, Duwig et al., 2014). The watershed drains the city of El Alto / La Paz with a population growth rate of 5.2% per year where most sewage is discharged untreated into the environment. The North Altiplano has unique physicochemical characteristics such as high altitude (3800 m), significant UV radiation, low oxygenated waters and semi-arid climate, with intense and highly variable rainfall, influencing the transfer, sorption and degradation processes of organic contaminants.

A screening of the main contaminants, including metallic trace elements and antibiotics was carried out during dry and wet seasons in strategic points of the river and groundwater systems of the Katari watershed. Resistance genes to the main antibiotic detected in the surface and ground waters were looked for in soils and surface waters.

The results showed the presence of high concentrations of sulfamethoxazole (SMX) and trimethoprim (TMP), antibiotics widely used for the treatment of diseases in humans and animals, usually in combination. Discharges of raw wastewater and treated wastewater from the waste water treatment plant were found to be the main source of these pollutants in the basin. Nevertheless, agricultural practices as manure application of antibiotic-treated animals could also play a role on observed concentrations. This uncontrolled use of antibiotics had not only given way to antibiotic pollution of natural ecosystems, but also to the presence of antibiotics resistances genes: SMX bacterial resistance (SulI and SulII genes) were found all over the catchment, even in areas where anthropogenic activity is almost non-existent and free of antibiotic pollution.

Discharges of antibiotics in the environment arise not only at toxicological problem but they also impact the bacterial populations which can lead to the developments resistance. It is recognized as one of the most important world while public health problem (WHO, 2015). These results are linked to consumption patterns in the study site and the lack of pharmaceutical consumption regulation policies.

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Accelerated eutrophication in Lake Titicaca: Historical evolution, mechanisms, monitoring, and observatory approach

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Abstract :

During 1970-1990's, deep Lago Mayor and most of shallow Lago Menor were oligotrophic with high water transparency and strong nitrogen limitation. Greens and cyanobacteria (*Anabaena*) dominated the phytoplankton, except diatoms during the dry season, with low biomass and primary production. Windy and rainy periods drove nutrient enrichment seasonality. Discharges from Puno-Juliaca, the most populated urban center (< 350,000 inhab. in 2007) made Puno bay the most eutrophicated area, with floating *Lemna* proliferation.

Currently, the deep pelagic areas of Lago Mayor remain oligotrophic. However, shallow littoral areas of Lago Mayor and Lago Menor are becoming meso- to eutrophic. In Lago Menor, northern littoral villages generate diffuse and point sources of human contamination, while El Alto is responsible for the overwhelming uncontrolled contamination of Cohana bay. The 2015 extended rainy season provoked the first major phytoplankton bloom event, spreading harmless green *Carteria* unicell over Lago Menor northern part in March-April. Anoxy killed tons of *Orestias* fish, giant frogs *Telmatobius*, and aquatic birds. Blooms have been spotted since the 2000s on images from LANDSAT satellites and NASA International Earth Observatory Orbital Station. Yet, blooms cannot be predicted because they are not studied, nor their emerging conditions. Dinoflagellate *Ceratium*, an invasive species in South American freshwaters favored by climate warming, and a problem for water treatment, is increasing in outer Puno bay, Lago Mayor and Lago Menor, occasionally forming blooms. Cyanobacteria *Limnoraphis* (syn. *Lyngbya*) predominate in Puno bay. Regime shifts occur between phytoplankton and macrophytes as typical in shallow lakes. Controlling accelerated

eutrophication requires studying Lake Titicaca biogeochemical and ecological functioning, food web topology between plankton, fish, and macrophytes, and the drivers of regime shifts.

Facing the urgency, the e-TTKK consortium is implementing a comprehensive program combining high-frequency *in situ* monitoring, biannual whole-lake campaigns, innovative state-of-the-art high-precision Sentinel satellite imaging, GIS GeoVisor IIGEO/UMSA, and Lake Titicaca Binational Observatory. This will improve our knowledge on Lake Titicaca eutrophication, anticipate extreme events, and advise decision makers, scientists, and the general public to take the best-coordinated actions for resources management and restoration of degraded areas, in response to global change.

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Session 2: Arsenic issues in the Andes

Session 2.a. Arsenic biogeochemistry and contamination of aquatic ecosystems of the Andes region

Keynote lecture

Biogeochemistry and arsenic contamination in Chilean Andean aquatic systems and its implications on trophic chains.

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Abstract:

Arsenic Biogeochemistry is the result of varied processes that occur both simultaneously and continuously. These processes include: a) arsenic emissions from natural and anthropogenic sources; b) chemical and biochemical transformation and c) transport, mobility and bioavailability through heterogeneous environmental compartments (lithosphere, pedosphere, biosphere, hydrosphere and atmosphere).

The main sources of arsenic in Chilean Andean aquatic systems derive from the natural geothermal activity together with anthropogenic metallurgical mining activity. This way, in water, essential for the survival of the species, arsenic concentrations are highly variable and influenced by the geological formation traits. High concentrations of arsenic in groundwater are due to erosion and leaching of arsenic from arsenic rich geological formations, thermal springs as well as active mining and abandoned mine site residues.

In water, arsenic is usually found as inorganic oxyanions forms such as arsenite and arsenate. Methylated arsenic species are percentage wise less important in this medium. The distribution of different arsenic forms depend on the water's acid base and oxide reducing conditions.

Health problems associated to chronic As exposure through water have been extensively studied which result in skin lesions, cardiovascular disease, reproductive problems, neurological disorders and the generation of different types of cancer. On the other hand arsenic from water can also be incorporated, bio-transformed, bio-accumulated through the food chain thus creating health problems for the population in Chilean Andean.

This presentation will analyze available data, will review and discuss the main biogeochemical processes that explain the natural and anthropogenic arsenic in aquatic ecosystems in the Chilean Andes and finally will describe the impact of the above mentioned on trophic chains.

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Human arsenic exposure in Bolivian Andes: Where do we stand?

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Abstract:

Inorganic arsenic is a ubiquitous metalloid, with well-known toxic properties for human health. In many regions of the world, human arsenic exposure is identified as a public health problem because of its presence in drinking water and certain food. Even at relatively low levels, regular consumption of contaminated water is considered to increase the risk of cancers in different organs, such as urinary bladder, skin, and lung, probably also liver, kidney and prostate. More recently, multiple other chronic diseases have been associated with environmental arsenic exposure, such as diabetes, cardiovascular diseases, as well as impaired immune function and child development. The WHO guideline water arsenic concentration is 10 µg L^{-1}. Certain plants, rice in particular, is known to easily take up arsenic from the soil.

In the south regions of Bolivia, concentrations above 100 µg L^{-1} have been found in traditional wells or tube-wells used by the population on a daily basis without having a clear knowledge of the situation. This arsenic originates from leaching of arsenic in sediments and volcanic rocks of geogenic origin (Muñoz et al, Ramos OE et al).

Preliminary results of an ongoing cross sectional study have confirmed the human exposure in some villages south from Poopó Lake. Concentration between 10 and 150 µg/L were observed in tap water, traditional wells and tube-wells. The concentrations in collected urines samples, a marker of the total exposure through drinking water and food, confirmed exposure in the low to medium range, known to be associated with increased risk of adverse health effects.

The lack of knowledge by medical staffs of the region and the absence of overt symptoms will be discussed.

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Arsenic removal metabolism, genotoxic damage and genetic susceptibility in humans

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Abstract:

Exposure to arsenic (As) is a major problem in many parts of the world. In fact, it is estimated that more than 100 million people are exposed to arsenic, mainly through contamination of groundwater. Chronic arsenic exposure is associated with adverse effects on human health, such as cancer, cardiovascular diseases, neurological diseases and the rate of morbidity and mortality in the exposed population health is alarming.

Arsenic has a strong genotoxic potential and is capable of causing DNA damage such as aneuploidy; micronucleus formation, chromosomal aberrations, deletion mutations, sister chromatid exchange and DNA-protein crosslinks. Several mechanisms have been hypothesized to explain the cause of this DNA damage, but more studies are needed to establish the mechanism on the basis of genetic damage induced by arsenic in order to develop specific treatment strategies for related disorders with arsenic. In addition, epidemiological studies have found that there is a high inter-individual variability in susceptibility to arsenic-induced toxicity. Several studies have established the influence of genetic polymorphisms in susceptibility to arsenic through modulation as metabolism, detoxification and DNA repair.

Preliminary results from a pilot study in three villages of Poopo Lake showed that there is DNA damage in one population measured by comet assay, the parameters of comet assay: tail moment, moment olive and percentage of DNA in tail showed a signficative difference between villages. It is necessary to increase the sample size to confirm the results found and to and to correlate with other variables in study.

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Arsenic and trace elements in mine impacted systems, Poopó and Antequera sub basin, Bolivia

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Abstract:

Mechanisms of arsenic (As) and trace elements (TE) release in the surface and groundwater were studied in Poopó Lake Basin at the Bolivian Altiplano. Hydrochemical data for surface water and groundwater were collected. There is a large variability of the concentration of As and TEs in the groundwater in the five different regions within the basin. Two generalized trends for As distribution were identified in groundwater: (i) high concentrations are found in the arid zone (100 – 250 µg/ L) in the southern (region III) and in the northwestern (region V) regions, and (ii) low concentrations (<50 µg/ L) are found in the remaining part of the basin (region I, II and IV). However, the spatial distribution within these regions needs to be investigated further.

A geochemical approach was applied to understand the factors controlling the mobilization of As and TEs in mining areas of the Poopó and Antequera River sub-basins (region II) in the Poopó Basin. A total of 52 samples (surface, groundwater and thermal water) were collected during the rainy season. Arsenic, Cd and Mn concentrations exceed WHO drinking guidelines and Bolivian regulations for drinking water in 28 groundwater samples, Factor analysis was applied to 18 hydrochemical parameters of 52 samples. Five factors for groundwater (plagioclase weathering, dissolution of gypsum and halite, TEs mobilization at acidic pH, sulfide oxidation, and release of As). Four factors for surface water data (weathering and mobilization of TEs influenced by pH, dissolution of evaporate salts, neutralization of acid mine drainage, and As release due to dissolution of Mn and Fe oxides). The As and TEs mobilized in these regions could affect the local water sources, which is a prevalent concern with respect to water resource management in the region.

At three transects (T1, T2 and T3) with intensive crop production in Poopó river sub-basin to study the distribution of TEs such as As, Cd, Cu, Pb and Zn in agricultural soils. The pseudo-total and bioavailable TE contents were determined by extraction with aqua regia, DPTA extractions for As, Cd, Cu, Pb and Zn, and As by a sequential extraction, respectively. The total concentration of TEs in soils suggested high background contents related to the presence of the polymetallic belt in the study area. The correlation between Fe_{regia}/Mn_{regia}-As_{regia}, Cu_{regia}, and Zn_{regia} ($p< 0.01$) seem to be related to the formation of secondary iron oxides with capacity to strongly adsorb these TEs. Carbonate species are also established as potentially bioavailable, their negative ($r^2= -0.51$; $p< 0.01$) Spearman´s rank correlation between soil pH-As_{DTPA} suggests that the retention of TEs as carbonate is not dominant, this matched with the results of step 1 (As fractionation). The DTPA method extracted less than 2% (step 1) and < 10.0% (step 2) of the total As content, as a potentially mobilized fraction, which could be transferred to crops or dissolved in groundwater. As, Cd and Pb can be accumulated in the soils due to amorphous and crystalline Fe oxide surfaces present in the soils, which was confirmed by the fixed arsenic fractions (fractions 3, 4 and 5).

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Hidrogeoquímica del Arsénico en el Altiplano Central de Bolivia

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Abstract:

A nivel mundial se ha estimado que alrededor de 200 millones de personas están directamente afectadas por la presencia de arsénico (As) en el agua empleada para consumo [1], sin embargo este número se incrementa a medida que nuevas áreas en el mundo son investigadas. La presencia de arsénico (As) en el agua empleada para el consumo es uno de los mayores problemas para la salud humana debido a su elevado potencial para causar enfermedades cardiovasculares y diferentes tipos de cáncer de los cuales los más comunes son el cáncer de piel y de vejiga [2].

En Bolivia pocos estudios han investigado la presencia de As en el agua de consumo, siendo las investigaciones más sobresalientes las llevadas a cabo en el Altiplano Boliviano [3, 4, 5, 6, 7, 8]. El área ubicada al sur de la cuenca del lago Poopó ha sido identificada como una de las áreas más afectadas por contaminación natural de As, en esta área se ha encontrado que el 90% de los pozos de agua contienen concentraciones de As que sobrepasan hasta en 60 veces el valor máximo permisible establecido en normas nacionales e internacionales [10 μg/L] [9, 10].

El presente estudio ha logrado identificar que ciertas formaciones geológicas distribuidas alrededor del lago Poopó son potenciales fuentes naturales de As, especialmente las rocas volcánicas tipo ignimbritas y las rocas sedimentarias tipo esquistos y calizas. El contenido de As en muestras de ignimbritas es de 1.2 mg As/kg mientras que en las calizas es de 27 mg As/kg. Los procesos de meteorización física fraccionan los diferentes tipos de roca y generan inmensas cantidades de sedimento que desplazados por el viento y el agua de escorrentía son transportados y redistribuidos a lo largo de la planicie altiplánica. La infiltración del agua meteórica a través de la roca volcánica permeable conjuntamente con el largo tiempo de residencia del agua subterránea y la consecuente recarga/descarga durante la época de lluvias causa la liberación de elevadas cantidades de As al agua superficial y subterránea. Por otro lado, los procesos de meteorización química incorporan sodio a la fase acuosa, incrementan su alcalinidad y suben el pH, favoreciendo de esta manera la movilización del As y su incorporación al acuífero subterráneo.

Las elevadas concentraciones de As encontradas en pozos ubicados en las planicies alrededor del lago Poopó señalan a los sedimentos como las fuentes principales de As, sin embargo, existen variaciones significativas en las concentraciones de As en pozos vecinos lo que indica que las fuentes de As no están homogéneamente distribuidas a lo largo de la planicie. El contenido de As en los sedimentos circundantes al lago Poopó es de hasta 51 mg As/kg, sin embargo no todo el As presente en el sedimento es movilizado a la fase acuosa, los mecanismos geoquímicos más probables para la movilización del As en el sedimento son el intercambio iónico, la desorción de As de fases minerales de hierro causado por el elevado pH y la competitividad con el Si por sitios de adsorción.

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Session 2.b.: Workshops

Open sessions and discussions

Workshop 1: Arsenic and mercury speciation:

- Hg speciation analysis: from sampling to speciation analysis (E. Tessier)
- Inorganic As speciation (M. R. Ormachea Muñoz & O. Ramos)
- Organic As speciation: advances and limits (G. Lobos)

Workshop 2: Paleoenvironmental studies in the Andean altiplano:

- Paleoclimate reconstructions
- New tools & developments in paleo-environmental studies
- Human / environment interactions

Session 3: Historical reconstructions of the human-climate interactions in the altiplano: implication of archeological purposes

Session 3.a. Paleo-environmental reconstruction of Altiplano's archives

Keynote Lecture

Holocene Paleoclimatic and Paleoenvironmental History of the Lake Titicaca Basin

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Abstract:
Lake Titicaca, Bolivia/Peru has a paleoclimatic record extending back more than 0.4 Ma (Fritz et al., 2007). High-resolution Holocene paleoclimatic records from multiple proxies and locations within the lake (Cross et al., 2000, 2001; Baker et al., 2001; Tapia et al., 2003; Baker et al., 2005; Fritz et al., 2006) and from other sites within the basin, such as Lago Umayo and Lago Lagunillas (Ekdahl et al., 2008; Baker et al., 2009), have been used to infer lake-level and climate variation at orbital to multi-decadal scales. At multiple temporal scales, large precipitation increases and deep fresh conditions in the lake are synchronous with North Atlantic cold events (Baker et al., 2001; Baker and Fritz, 2015). Reconstructions for the early- to mid-Holocene from diatoms and geochemistry show ocillations between intervals of moderately high and low lake level paced at millennial scales, with the lowest lake level, as much as 85 m below modern (Seltzer et al., 1998), and the highest salinity from ~6-5 ka. During most of the mid-Holocene, the two basins of Lake Titicaca were hydrologically isolated, and much of Lago Huiñaimarca was dry. After 5 ka, lake level began to rise, and ~4.5 ka the large lake overflowed via the Straits of Tiquina into Lago Huiñaimarca. Lake level in both basins fluctuated on a century to sub-century scale for the next few thousand years, followed by substantive lake-level rise, freshening, and outflow via the Rio Desaguadero after ~2.0 ka.

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Multi-proxy reconstruction of changes in water level and organic matter sources related to climate change over the Holocene (Lake Titicaca, Bolivia)

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Abstract:
Over the late Holocene, five periods of low lake Titicaca level have been identified resulting from negative moisture balance for the northern Andean Altiplano (Abbott et al., 1997; Mourguiart et al., 1998). The aim of our project is to refine these water level variations and decipher the influence of climate change on lake productivity and catchment input over the entire Holocene.
To reach these objectives, a sediment core from the Chua basin (Lago Huiñaimarca) was sub-sampled at high resolution and analyzed for multi-element geochemistry (36 major/trace elements), isotopic composition of sulfur as well as for the molecular composition of organic matter (OM). This latter was determined using a new method based on pyrolysis-gas chromatography-mass spectrometry (Tolu et al., 2015). Beyond its rapidity and requirement for small sample mass (<1 mg), which are criterions for multi-proxy and high-resolution paleo-reconstruction, this method yielded semi-quantitative data on 163 organic compounds. These compounds belong to different biochemical classes (e.g., carbohydrate, lipid, chlorophyll) and are of different origins (e.g., plant, algal) and degradation status (Tolu et al., 2015), making it possible to both use specific biomarkers and investigate changes in the overall OM molecular composition.
The sediments deposited between ~ 8000 and 6000 BP were strongly enriched in (poly)aromatics, which are indicative of OM polycondensation during degradation, i.e. 36 ± 10 vs 7 ± 3 % for the last ~ 5000 years. Moreover, only the degradation products of, and no, high molecular mass carbohydrates/polysaccharides, proteins and chlorophylls (e.g., (alkyl)furans, (alkyl)pyrroles) could be identified. This major change in the OM molecular composition coincided with a drastic change in sedimentation rate (~ 4000 year in the first 63 cm and ~ 2000 year over the last 100 cm) and suggests low lake/catchment productivity and/or highly degradative environment between ~6000 and 5000 BC (very dry event).
Based on both geochemical and OM proxies, the last ~ 5000 years could be splits into 3 main units as deduced from diatom reconstruction of Weide et al. (2015). From ~ 5000 to ~ 3000 BP, the Chua basin was a wetland due to dry climatic conditions. From our data, this period appears to present (i) the highest algal production, probably from Characeae (high carbonates content); (ii) lower plant OM due to lower input from the catchment/lake shoreline (lower content of refractory elements); and (iii) higher proportion of degraded OM due to oxic conditions. This unit is surrounded by two shell layers which were characterized by biomarkers for plant growing in humid environments and lower proportion of degraded OM due to less oxic conditions (higher water level). The sediments of the last c. 3000 years were deposited under deep lake conditions, but our data, and especially $\delta^{34}S$, Mn and Mo contents and ratios for OM freshness, showed additional water level fluctuations which are coherent with recent reconstructions based on diatoms (Weide et al., 2015).

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Paleoclimatic records from Bolivian glaciers

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Abstract:

In the Andes, especially in Bolivia, the glaciers studies allows to reconstruct the evolution of past climate at different time scales, from seasonal variations to the Last Glacial Maximum. At short scale with instrumental data, the study of ablation/accumulation processes were used to establish the relationships between glacier mass and surface changes and weather/climate variables such as El Niño events or recent global warming. In this recent period, the glaciers show strong general retreat all over the Andes. The evolution of the glacier surface, observed by aerial pictures or reconstructed from different moraine stages informs us about their evolution since the Little Ice Age or longer with some fluctuations in a shrinking phase. Ice cores extracted from highest Andean glaciers extend these reconstructions to the Last Glacial Maximum.

Contexto histórico de bofedales del Valle de La Paz y zonas aledañas desde una perspectiva palinológica

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Abstract:

Se ha realizado la reconstrucción de la vegetación mediante métodos palinológicos en lagunas y/o bofedales de los andes paceños (≥4000m). En este trabajo presentamos resultados del análisis de un perfil realizado en un bofedal cerca del glaciar de Charquini de la Provincia Murillo (4700 m de altitud). La calibración de análogos actuales muestra que el bofedal está poco antropizado, dominado por cojines de *Oxychloe andina*. En la superficie del suelo de bofedal dominan palinomorfos altamente relacionados con especies de la vegetación actual. En pastizales aledaños dominan pólenes de especies locales y extralocales provenientes de los Yungas. La presencia de polenes extralocales indica baja cobertura vegetal, que facilitó la deposición de polen trasportado por corrientes de aire. El perfil de sedimento alcanzó 4m de profundidad; la datación de ^{14}C más antigua a 3,3 m, corresponde a 4980 yr cal BP (años después del presente), donde se registró elevado porcentaje de polen de Poaceae indicando un periodo húmedo, esta condición permanece estable con algunas fluctuaciones entre 995 y 586 yr cal BP. La disminución más drástica de Poaceae (>humedad) se registra a los 280 yr cal BP, este patrón coincide con un perfil realizado en un bofedal en Tuni Condoriri, interpretándose ésta reducción como un efecto de la Pequeña edad de hielo ocurrida en la segunda mitad del siglo 17 (año 1650). A partir de este evento se registra un incremento de Asteraceae (> temperatura) llegando a un punto máximolos últimos 50 años. Por otro lado, hace 900 -1400 AD (1100 – 600 yr BP) se registran porcentajes de polen de Chenopodiaceae asociados a cultivos de *Chenopodium quinoa* probablemente cultivados en el último periodo Tiwanacota que habitaban zonas aledañas al área de estudio coincidente con otros estudios palinológicos realizados en Tiquimani.

Reconstrucción, Palinología, Charquini, Poaceae/Asteraceae, quinua

Cambios de Vegetación y eventos de perturbación por actividad antrópica en base al estudio de dos perfiles de sedimento de un Bofedal en Escalerani (Cordillera Real)

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Abstract:

Se ha realizado un estudio palinológico de un perfil de sedimentos de 1 m de profundidad. La muestra se sitúa en un tipo de vegetación clasificada como Paramo yungueño y esta próxima a un remanente de bosque de *Polylepis*, en el este de la Cordillera Real, Escalerani. Los resultados nos muestran picos de carbón hace 540 cal yr BP con un subsecuente incremento hasta la actualidad este resultado coincide con el inicio de la colonia y apoyados con la reducción en la concentración de taxones polinicos, con una dominancia de polen de *Plantago*, que en la actualidad el taxón mayor representado en el Bofedal., también tenemos otro pico de carbón hace 3655 cal yr BP y la aparición de una gramínea, posiblemente Festuca, que podrían indicar el comienzo de la cría de ganado camélido en un área cercana.
Además la interpretaciones de la relación Poaceae/Asteraceae, muestran que antes de 7505 cal yr BP (años antes del presente) se tenían un periodo más húmedo, seguido de un cambio gradual de 80 a 30 % en el presente, excepto en dos periodos 3650 y 500 – 620 cal yr BP con un incremento del 100% y 35% respectivamente. El estudio de Sandoval (2011) muestra que la dispersión del polen de *Polylepis* no llega a distancias mayores de 100 m, entonces podemos asumir que la presencia de polen de *Polylepis* hace 5600 cal yr BP, podría indicarnos que el bosque tuvo probablemente una extensión mayor que en el presente. Actualmente estamos realizando estudios de C13/N15 y XRF para entender que pudo haber pasado con los cambios en el clima.

Palabras clave: Escalerani, polen, carbones, isotopos.

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THE PRESENCE OF ARSENIC IN THE CHINCHORRO CULTURE MUMS

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The Atacama Desert features a dry climate associated with high levels of salinity in its soils. Furthermore, it comprises high concentrations of arsenic in its water resources (river, wells and springs). It is well known that these conditions have favored the body mummification of the Chinchorro culture which is found throughout the coastal area of the Arica and Parinacota Region.

The major content and trace elements were determined in order to understand their distribution in filler material, bones and mummy hair belonging to the Chinchorro culture. The study samples were obtained from various areas such as Camarones, Morro, Maestranza Chinchorro, Maderas Enco, Playa Millar and Azapa, among others. The Analytical methodology was as follows: atomic absorption spectrophotometry with hydride generation (AAS-HG), energy dispersive X-ray fluorescence spectrometry (EDXFS) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

The results obtained showed that there are important differences in the elements and their relative proportions in the bones, the filler material and the hair. Furthermore, it was established that the inorganic materials used for internal filling and exterior painting of the mummified bodies, do not have the same distribution of chemical elements (both major and trace) indicating that these materials do not come from a common source, even for samples located in the same burial site.

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Session 3.b. Archeology: historical human – environment interactions

Keynote Lecture

Utilización del espacio litoral y fluctuación del lago Titicaca entre el 300 d.C. y el 1600 - Excavaciones arqueológicas subacuáticas de un espacio portuario precolombino.

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Resumen:

La identificación y estudio de un primer espacio portuario precolombino en la Isla del Sol – Utilizado durante el periodo Tiahuanaco (500-1500) e Inca (1430 -1532) – aportan nuevas informaciones sobre las diferentes tradiciones de navegación nativas y la naturaleza de la ocupación del litoral lacustre. Los resultados demuestran que el espacio portuario Inca no se encuentra en el mismo emplazamiento que en los periodos anteriores, no solo porque el nivel del lago era diferente (paisajes naturales distintos), sino también porque la utilización antrópica del lago no respondía a las mismas dinámicas socio-económicas, políticas y rituales (paisajes culturales diferentes).

Desde un punto vista natural, el estudio de la acumulación sedimentaria lacustre asociado a los objetos arqueológicos permiten identificar los paleo-fondos y las paleo-orillas: el nivel del lago durante el periodo Inca era casi idéntico al nivel actual, pero el del periodo Tiahuanaco era, por lo menos, cuatro metros más bajo. La identificación del espacio litoral Tiahuanaco abre pues nuevas perspectivas de investigación excepcionales, pues existen más de 300 km de costa lacustre, en la parte boliviana del lago Titicaca, que jamás han sido excavadas ni estudiadas.

Desde un punto vista cultural, la naturaleza y la diversidad de los objetos arqueológicos encontrados bajo el agua, permiten abordar diferentes problemáticas de investigación desde una perspectiva diacrónica: (1) La del estudio de las prácticas asociadas al espacio litoral (prácticas funerarias, explotación de los recursos lacustres, trabajo del cuero y de la lana de llama), (2) La de las técnicas de navegación en el lago (barcos y rutas navegables), y (3) la de las circulación de los bienes y las personas entre el espacio insular y el continente (comercio y peregrinaje).

Keynote Lecture

Recent contribution of terrestrial investigation of the Project "Archeology and Paleo-environment of Río Guaquira – Tiwanaku"

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Abstract:

Tiwanaku, the focus of many major archeological studies, has been an important site for the understanding of Andean prehispanic cultures. This is because archeologists have restored the internal organization of the city through its various stages of development. However, the causes of desertion of this site between the 10th century and the second half of the 12th century remain uncertain. The climate change of the Altiplano is well known because of the contribution of paleoenvironmental data acquired from Lake Titicaca. However, the evolution of landscape and the sediment dynamics of rivers along this major archaeological site have been little studied. The absence of geoarcheological, geomorphological, and paleoenvironmental research on the fluvial network of the Altiplano is a gap that can be filled by our multi- and interdisciplinary research program.

The aim of our work is to conduct a combined study of the cultural and social development of the societies of Tiwanaku, with the landscape evolution in the catchment basin of the Río Guaquira - Tiwanaku for the recent Holocene (from ~ 5000 BC to the present day).

Sedimentary records from alluvial formations allow us to reconstruct the evolution of the landscapes that ancient societies have inhabited. The sedimentological and geophysical analysis of boreholes throughout the floodplain of the River Guaquira - Tiwanaku, crossed with extensive geophysical surveys will help to restitute the evolution of alluvial morphology in a sector of the Bolivian Altiplano still little explored. The data from old and new maps will refine the identified sedimentary forms. Finally, the contribution of data from biological proxies (pollen, charcoal, ostracods, diatoms, bivalves ...) will characterize the evolution of the morphology and composition of the vegetation and the wetlands.

Analysis of the geographical distribution of human settlements within the watershed coupled with the study of construction techniques will highlight the environmental exploitation strategies of Tiwanaku cultures. In addition, analysis of ceramic and lithic material collected during excavations and archaeological surveys will determine the origins of raw materials. The information gathered during our study will be crossed with Geographic Information System (GIS), which will provide new data on the relationships that ancient societies developed with their environments.

With this multi-disciplinary approach, innovative in the region, we propose to reconstruct the landscape morphology of one of the most beautiful sites in the Bolivian Altiplano. The use of new research techniques will help to develop a long-term collaboration with research organizations in Bolivia and South America through the training of students and through participation in local research projects.

Desarrollo de las tecnologías prehispánicas y su correlación con las reconstrucciones ambientales de los periodos Formativo y Tiwanaku en la Cuenca del Lago Titicaca, Bolivia

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Abstract:

En los últimos 40 años el área andina, y en particular la Cuenca del Lago Titicaca, ha sido objeto de numerosos estudios con el objetivo de contar con una reconstrucción paleoambiental que refleje confiablemente lo acontecido en los últimos 25.000 años. Buena parte de esta reconstrucción ha sido lograda con éxito; sin embargo los cambios acontecidos en los últimos 4.000 años aún requieren un mayor refinamiento. Las investigaciones arqueológicas recientes han empleado estas reconstrucciones y las han correlacionado con los diferentes momentos de cambio observados en el registro arqueológico, principalmente en torno a la emergencia y desintegración de la entidad política de Tiwanaku. El presente trabajo hace acopio de los datos colectados en las investigaciones del sitio de Wankane y su entorno directo ubicado en la región de Jesús de Machaca, al sur del Lago Titicaca para examinar el uso de tecnologías agrícolas prehispánicas como los reservorios para cosecha de agua (qochas o qotañas) durante los periodos Formativo Tardío y Tiwanaku, discutiendo las condiciones climáticas que habrían favorecido o propiciado su empleo.

Four thousand years of climate change, cultural development, and fishing in Lake Titicaca

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Abstract

The Lake Titicaca Basin is one of the few regions in the world where both primary village and state formation occurred in prehistory. Although agricultural intensification has been proposed as the central engine fueling these processes, fish and other aquatic resources were significant but little-understood components of the region's ancient economy. In this presentation, I summarize the results of the zooarchaeological study of fish remains from archaeological sites situated in the Taraco Peninsula located in the southeastern shore of Lake Titicaca (Capriles 2013; Capriles et al. 2008, 2014). Specifically, I use the result of faunal analysis from the sites of Chiripa, Kala Uyuni, Iwawi, Sonaji, and Kumi Kipa carried out in the context of the Taraco Archaeological Project (Hastorf 2008) to discuss the interplay between fishing, environmental change, and the emergence of the Tiwanaku state in the Lake Titicaca Basin. Results suggest that fishing comprised a significant component of the region inhabitants' diet starting about 3500 years ago. The intensity of fish procurement, however, varied through time and independently of both climatic and population change. The variation in fish consumption through time was a product of group and individual decisions to optimize resource use in a context of dynamic environmental and sociopolitical variability.

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